Seeing stars with SOFIA

Flying through Earth's stratosphere, NASA's airborne astronomical observatory will offer advantages over ground- and space-based telescopes

by **Ben Iannotta**
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On a starry night in October 2004, two aerodynamically designed doors will blink open on the fuselage of a refurbished Boeing 747 airliner cruising at 41,000 ft. Infrared heat energy from the cosmos will strike a 2.5-m mirror housed inside the fuselage of the Stratospheric Observatory for Infrared Astronomy (SOFIA). For the first time in 10 years, the U.S. will be back in the business of airborne infrared astronomy.

NASA managers have debated, reviewed, renamed, stopped, and restarted the SOFIA airborne telescope project for the better part of three decades. Work on the $380-million plane is now under way, says Clifford Imprescia, program manager at NASA-Ames, which will be SOFIA's home base. The effort, the program manager adds, is firmly fixed in NASA's budget plan.

Engineers and technicians are refurbishing the retired United Airlines jet inside a hangar at L-3 Communications in Waco, Texas. The plane is a retired 747SP with a shorter fuselage and longer tail than a normal version of the aircraft. SOFIA officials chose it because it also has a greater range and can stay in the air longer for more observation time, says Imprescia.

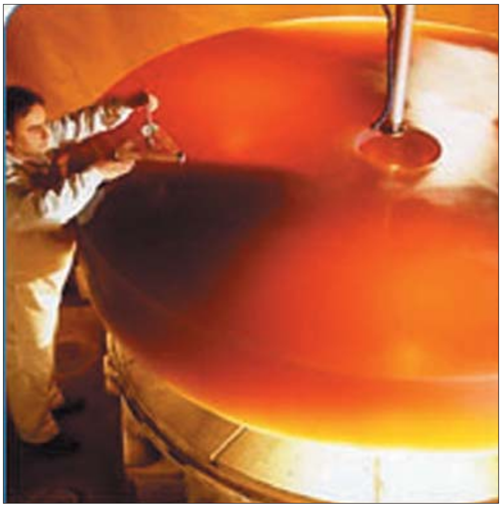
Meanwhile, MAN Technologies in Augsburg, Germany, is nearly finished building SOFIA's telescope, which is due to arrive in the U.S. in early August. In Waco, engineers will install the telescope onto SOFIA piece by piece in a painstaking nine-month process.

Officials from NASA and DLR, the German space agency, have agreed to share funding responsibilities for SOFIA. NASA will cover 80% of the costs, DLR 20%. The Universities Space Research Association of Columbia, Md., a nonprofit consortium of U.S. scientists, is overseeing work on the NASA side. United Airlines has signed on to operate and maintain SOFIA.

Staying above water

For infrared astronomers, SOFIA is the long-awaited successor to the Kuiper Airborne Observatory, a remodeled C-141 cargo plane that took infrared images of the cosmos from 1974 until its retirement in 1995.

SOFIA will gather invisible, far-infrared energy emitted from celestial objects at wavelengths of 50-200 μm. Most infrared energy is absorbed by water in the atmosphere, a phenomenon that limits ground-based infrared astronomy. SOFIA will solve that prob-



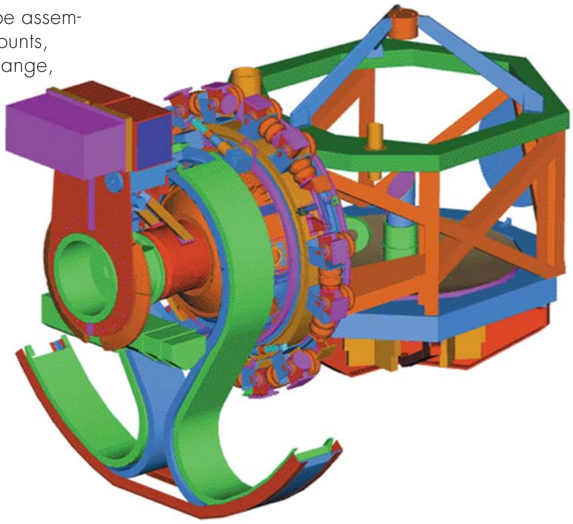
The Zerodur mirror blank weighs almost 2,000 lb. The blank will undergo a lightweighting process to reduce its weight without losing its structural integrity.

lem by flying in the stratosphere, above 95% of atmospheric water, says Imprescia.

The process of gathering infrared images and data will begin when SOFIA opens its doors and light strikes its main mirror. "The job of the telescope is to collect all of the photons that strike the mirror," explains Thomas Greene, the SOFIA project scientist at NASA-Ames.

Smaller mirrors will steer the photons to a single astronomical instrument at the base of the telescope. The instrument will sort the signals into meaningful images or spectral readings. An electronic data acquisition system will convert the data into digital forms that can be displayed on computer screens in real time for astronomers on the plane. These scientists will step aboard SOFIA with a specific observation plan, but in monitoring the readings, they might decide to change the plan in flight to focus on an unexpected finding, Greene says.

Of course, the astronomers also can elect to save the data for review later.



Rendering of telescope assembly shows bearing mounts, instrument mounting flange, and entire cable drape as visible from cabin.

Many flights, many missions

Unlike the Hubble Space Telescope, SOFIA will carry only one science instrument at a time. However, the plane has been designed so that technicians on the ground can swap one instrument for another "within just a few days," Imprescia says.

A committee of leading astronomers has identified nine instruments to ride on the aircraft for several weeks each. NASA managers plan to fly SOFIA for 8-hr missions, three days a week. The scientists will compete for observation time aboard the plane.

Some astronomers plan to capture stunning infrared views of star formation and other phenomena that would be invisible to the human eye. Others want to see readings from spectrometers that dice the infrared energy into its constituent spectra. Atoms and molecules have distinct spectral signatures that researchers can use to determine the chemical makeup of deep space, Greene explains.

SOFIA's images could provide evidence of planets forming around distant stars, says Greene. Spectral data could confirm predictions that organic molecules, including amino acids, are formed not only in the primordial muck of Earth-like planets but in space itself. SOFIA could produce tantalizing evidence that the molecular building blocks of life were delivered to Earth, or other Earth-like planets, perhaps by comets, the project manager says.

Other astronomers will focus closer to home, studying the atmospheres of planets in our own solar system. When a planet crosses in front of a star, light from the star makes the planet's atmosphere glow like the aura of a candle. Astronomers take advantage of this natural event, called occultation, to study the atmospheres of planets. Such an occultation, for example, enabled Kuiper to discover that Uranus has rings, although narrower and more subtle rings than those of Saturn.

"SOFIA really is going to give us the best window into a lot of aspects of the universe," Greene says.

After more than its share of programmatic ups and downs, the SOFIA program is on track to begin viewing the heavens in October 2004. Several months of test observations will precede the start of routine scientific observations in January 2005.

Complementing SIRTF

Over the years, SOFIA backers have had to explain why their aircraft was necessary when NASA was already funding development of an orbiting IR telescope called the Space Infrared Telescope Facility. NASA officials expect SIRTF to do for infrared astronomy what the Hubble Space Telescope has done for visible astronomy.

While not wanting to take on SIRTF, SOFIA proponents like to point out the advantages of flying a telescope aboard a plane. "With a space-based telescope, you are above the atmosphere. You can see billions of light-years, but you're in a certain orbit. With ground-based telescopes, you're stuck on the ground. The nice thing about being on an aircraft is that you can go anywhere in the world," Imprescia says. If a supernova pops up in the Southern Hemisphere, SOFIA can fly there.

Operational advantages aside, Greene says SIRTF and SOFIA each have distinct strengths in terms of infrared astronomy. SIRTF will operate in the cold of space, with its telescope housed inside a thermos-like container called a dewar. SIRTF will function at a temperature close to absolute zero, whereas SOFIA will operate at a relatively warm –60 F. As a result, SIRTF will be more sensitive than SOFIA to dim infrared energy, especially in the shorter IR wavelengths of around 10 µm, Greene says.

But SOFIA will view objects in superior detail or spatial resolution. The resolving power of a telescope improves exponentially as the diameter of its mirror expands. Kuiper's mirror was 0.9 m across, SIRTF's is 0.85 m, and SOFIA's will be a whopping 2.5 m—as big as Hubble's.

SIRTF's sensitivity is advantageous for discerning dim objects; for viewing bright ones, however, it is a liability. "SIRTF may be able to see more deeply, but on the brighter objects, it can get confused," Greene says. "On the brighter objects, SOFIA will excel."

This brighter category includes swirling masses of dust around young stars, called circumstellar disks. Although SOFIA will not actually see planets forming from this material, it might find indirect evidence of planetary formation. As young planets sweep up particles, the circumstellar disks should become asymmetrical, Greene says.

Overcoming the jitters

On the face of it, installing a telescope on an aircraft might seem less challenging than building a telescope to operate in space. But SOFIA must fly at 41,000 ft, in turbulence, with a hole in its side. Its telescope must stay pointed precisely on a celestial object.

Turbulence is the bane of the project. To avoid blurry pictures, the telescope must stay fixed on its target even when the aircraft jostles around it. Engineers at MAN Technologies in Germany will solve the problem by floating the telescope on a meter-wide spherical bearing. "The whole telescope is balanced around that sphere and controlled with a sophisticated torque control system," Imprescia says.

The system is a more advanced version of the one used on Kuiper. Of course, there are limits to how much turbulence the telescope can handle. "If the turbulence gets

Flying by night

If your eyes could see in the infrared, the swirling clouds of heat energy reaching Earth on a 70° day would look almost identical to the infrared features on a 70° night. So, in theory, SOFIA could learn as much about the infrared universe during the day as after dark.

In practice, however, scientists will fly the plane mostly at night, for reasons that have more to do with technical necessity than astronomy, according to Thomas Greene, project scientist at NASA-Ames in California.

Perhaps most important, if sunlight struck SOFIA's telescope mirror, it could spell disaster. "If the sun hits the mirror, it reflects a focused beam somewhere—likely within the interior of the telescope chamber, which could start a fire," Greene says.

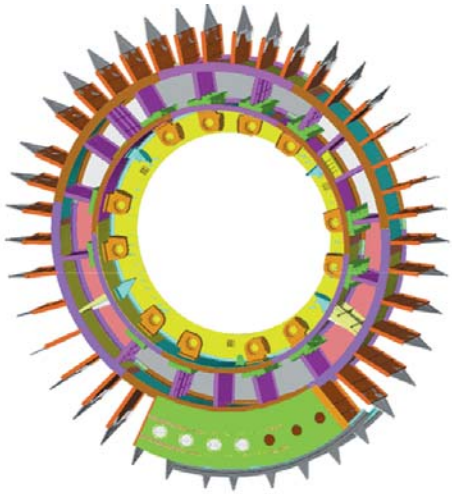
Second, unlike some infrared sensors, the SOFIA telescope will not be chilled inside a dewar flask. SOFIA will function at the ambient temperature, which typically is colder after dark. That means the telescope itself will emit less infrared energy, which makes it more sensitive at night, Greene explains.

Third, the telescope will rely on guide stars to stay locked precisely on its targets. A visible-light camera will sense these guide stars and feed the data into SOFIA's guidance system. "Unfortunately, there are very few such guide stars that can be observed during the day—none at visible wavelengths, and very few in the infrared," Greene says.

Even so, SOFIA probably will do occasional observations in daylight—for instance, of the inner planets. But it will do this work gingerly and with a restricted field of view.

"The only real way to keep the sun off the telescope is to control SOFIA's direction and change the elevation of the telescope and its door, both of which strongly affect where the telescope can look," Greene explains.

Polishing of the primary mirror, which measures 2.5 m across, is near completion.



The forward bulkhead will support the telescope assembly.

too great, it doesn't track the star anymore. But our experience with Kuiper was very encouraging," Imprescia adds.

Luckily, notes Greene, images in the far-infrared are derived from longer wavelength signals that are less susceptible to the jitter of turbulence.

Much of the engineering effort on SOFIA has gone into designing a door assembly that can slide open without ruining the plane's aerodynamic performance or causing image-distorting vibrations. NASA engineers started attacking this problem in the late 1980s. They did not have a lot of experience or operational data from which to draw. "You just don't open doors on airplanes flying at Mach 0.8 at 40,000 ft," notes Imprescia.

SOFIA engineers built a model of the door-fuselage assembly and tested it in wind tunnels at Ames and at the University of Washington. The biggest concern was that air rushing over the fuselage might pour into the unpressurized cavity housing the telescope, and that this would cause pressure fluctuations and acoustic vibrations that would distort the SOFIA images.

"Say you're driving your car down the highway. If you open your window a certain amount, you get a vibration that affects your ear drums," Imprescia explains. "We had to reassure ourselves that wouldn't happen with SOFIA."

The door assembly will slide open in two pieces like an eyelid. The rear edge of the opening is aerodynamically shaped like a ramp to direct the air back over the fuselage. In addition, the doors will move with the telescope as it swivels around the cavity. That way, they will stay flush with the telescope tube to prevent a gap that could disturb the flow of air.

The model passed all the wind tunnel tests. "It was a design challenge, but now it's basically done," Imprescia says.

Because the aircraft has undergone such extensive modifications, NASA managers must apply for an airworthiness certification from the Federal Aviation Administration. They plan to do so in 2003.

A new attitude

One of the biggest differences between SOFIA and space-based telescopes is the attitude program officials have toward new technologies, SOFIA officials say.

If an instrument fails on SOFIA, the pilot can fly back to Ames and technicians can plug in a new instrument. This is a luxury engineers do not have on a space telescope.

Developing missions for SOFIA "is a little less stressful than developing a spaceflight mission. The nice thing about SOFIA is that it comes back. We can keep improving it. Things don't have to work perfectly from the start," says Greene, who has also worked on astronomy satellite projects.

In fact, part of the mission of SOFIA is to test new technologies that might revolutionize astronomical instruments and eventually find their way onto spacecraft. "In space, failure is not tolerated. Here, failure is part of the experiment—as long as we can fix it," Greene says.

In particular, SOFIA will test new types of radiation-sensitive infrared detectors and receivers before they are flown in space.

One experimental instrument is called HAWC, for High-Resolution Airborne Wideband Camera. It is being built at the University of Chicago and will use new detectors. Another is called FORCAST, or Faint Object Infrared Camera for the SOFIA Telescope.

In addition to testing potential new space hardware, astronomers also hope SOFIA will produce results that scientists can study with space probes or spaceborne observatories. A case in point could be Kuiper's discovery of the Uranus rings. In 1977, as the planet approached a star during occultation, astronomers noticed a slight dimming of the energy, as though something outside the surface of Uranus were obscuring the light. In 1986, NASA's Voyager 2 probe passed close to the planet and produced images of 11 faint rings, two more than astronomers had anticipated from the Kuiper data.

Infrared astronomers like Greene are anxious to get back into business, and they expect the SOFIA findings to be at least as important as Kuiper's. "We're counting on it," Greene says.